Parametric Analysis of Corrugated Sandwich Panels

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Abstract- *Present mechanical industries aim to manufacture the best product by improving the mechanical properties of the material and by reducing the weight of the component which is obtained by choosing different material combinations and by replacing the existing models with the composite structures. Extensive research is focused on shape optimization in the process of engineering design which has ample contribution towards cost, selection of material and time saving. The purpose of dimensional and shape optimization is to determine the optimal shape and dimensions of a continuum medium to maximize or minimize a given criterion such as weight to volume ratio, minimization of stresses, deflection etc. Researchers are extensively adopting the computer aided optimization in solving such problems. In the past few decades a number of innovative approaches are developed and widely applied in the design optimization such as genetic algorithms, practical swam analysis, Ant colony algorithm and many more.*

Design of experiments (DOE) has become an important methodology that maximizes the knowledge gained for experimental data by using smart positioning of points in the space. The methodology provides a strong tool to design and analyze experiments; it eliminates redundancy observations and reduces the time and resources to make experiments. DOE statistical techniques are useful in complex physical processes, such as determination of geometrical dimensions, Shapes, selection of material combinations etc in many design processes. In the present study one such technique adopted is Taguchi method. In this method, the parameters identified for fabrication of corrugated panels are metal sheet gauge, core height, core materials, and core shape. The effect of individual parameters under three point bending is tested using ANSYS workbench.

Keywords- three point bending is tested using ANSYS, Design of experiments (DOE), computer aided optimization, gauge, core height, core materials, core shape.

I. INTRODUCTION

Ever increasing demand on engineers to reduce production costs and to withstand competition has prompted engineers to look for rigorous methods of decision making, such as optimization methods, to design and produce products both economically and efficiently. Optimization techniques, having reached a degree of maturity over the past several years, are being used in a wide spectrum of industries, including aerospace, automotive, chemical, electrical and manufacturing industries. With rapidly advancing computer technology, computers are becoming powerful and correspondingly, the size and the complexity of the problems being solved using optimization techniques are also increasing. Optimization methods, coupled with modern tools of computer –aided design, are also being used to enhance the creative process of conceptual and detailed design of engineering.

The purpose of this dissertation is to Design & Fabricate a corrugated panel to overcome the drawbacks of the composite materials and to analyze the effect of various geometrical parameters on the flexural modulus of the material. In the present work spot welded metallic panels are used to optimize the geometry. Based on the analysis, panel structure parameters considered are Thickness of the sheet, Core height, Core shape, Panel size and Material constituents of panel face sheet, bottom sheet and spot welding pattern. The design of structures with optimal geometry includes sizing, shape and topology optimization.

The Flexural test measures the force required to bend a beam under 3 point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material’s stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature it is sometimes appropriate to test materials at temperatures that simulate the intended end user environment.

Von-Mises Stress:

The von Mises stress is often used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition. This is accomplished by calculating the von Mises stress and comparing it to the material's yield stress, which constitutes the Von Mises Yield Criterion. The objective is to develop a yield criterion for ductile metals that works for any complex 3-D loading condition, regardless of the mix of normal and shear stresses. The von Mises stress does this by boiling the complex stress state down into a single scalar number that is compared to a metal's yield strength, also a single scalar numerical value determined from a uni-axial tension test (because that's the easiest) on the material in a lab. It should be noted that this is not an exact science like, say F=ma. It is an empirical process, with inherent error and deviations. In fact, there is no hard & fast rule saying that metals must yield according to Von Mises yield criteria.

Experimental Procedure of Three Point Bending:

- Measure the dimensions of the specimen.
- Check the limit of the linear region of the steel plate (with no strain gauge)
- Open the computer and Install universal test machine and run the associated software.
- Prepare the Wheatstone circuit and connect to the cables of strain gauges to the defined slot in the previous experiment "Strain Gauge".
- Use the digital micrometer to take sample.
- Adjust the associated Installed program with displacement controlled experiment.
- Run the experiment.

1. Design of Panels:

The process of designing a corrugated panel includes the following considerations:

1. Selection of the Material for panels
2. Size of the panels
3. Gauge of the panels
4. Core height of the panel
5. Core shape of the panel
6. Spot Welding Pattern

Here discussion will be mainly about the material selection of the panel and gauge of the panel. The other specifications are taken into consideration as per the requirement. But the material selection is based on the different types of material compositions available. Gauges are also clearly specified according to the American standards.

2. Flow Chart of the Thesis:

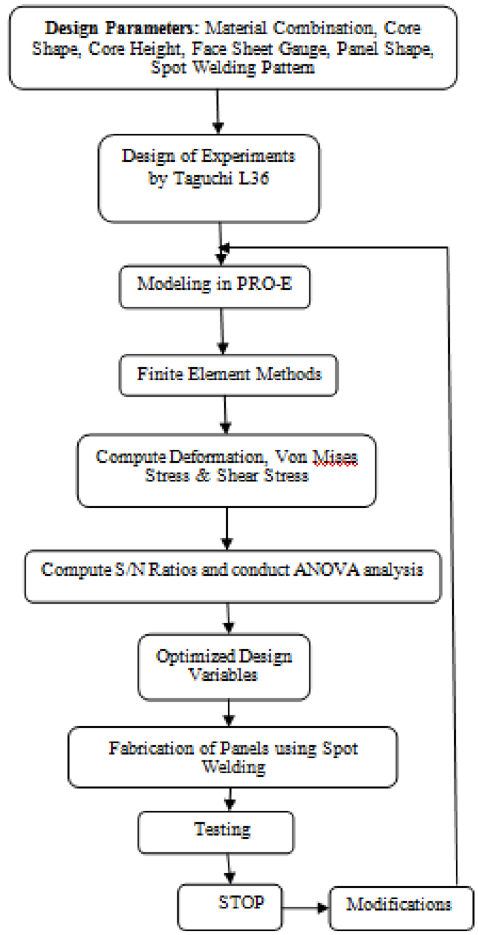

Figure 1. Flow Chart of the Thesis

3. Objectives of Thesis:

The main objectives of the present work are as follows:

- To design and fabricate corrugated sandwich panels using Taguchi Method and which involves selecting the input parameters in order to get the correct combination for manufacturing the corrugated sheets.
- To find out the best combination that is used for fabricating the panels through Taguchi Method. We need to conduct all the L36 experiments on the ANSYS workbench and find their respective Shear stress, Von Misses stress and Deformation.
- To design a special electrode that can be used for Spot Welding the panels. This includes finding the material that is used in welding the Stainless Steel sheets and the manufacture according to the Panels dimensions.
- To analyze the Von Mises Stresses, Shear stresses and deformation those are obtained from L36 experiments. Grey Relational Analysis is also done to find the optimum values of input parameters.
- To find out the compression load the panel can with stand.

II. Experimental Work

1. Introduction:

This chapter Design and Fabrication of corrugated panels deals with design of corrugated sandwich panels, the design of electrode, selection of work sheet materials, chemical composition of SAE 1010 Mild Steel and AISI 202 stainless steel, spot welding machine specifications. Design of experiments by Taguchi method using L36 experiments, experimental observation of three point bending test on ANSYS workbench are explained

Table 1. Chemical compositions of SAE 1010 Mild Steel

Percent composition (%)	C	Mn	Si	P	S
	0.0823	0.621	0.181	0.0129	0.0162

Table 2. Chemical compositions of AISI 202 Stainless Steel

Percent Composition (%)	C	Mn	Si	Cr	Ni	P	S
	0.15	7.5 to 10.0	1.00	17.0 to 19.0	4.0 to 6.0	0.06	0.03

2. Spot Welding Machine Specifications:

Spot welding machines are applicable in mass production lines of engineering industries, sheet metal, containers, drums, barrels, electrical equipment's, furniture, kitchen ware, automobile assembly, and ancillary lines, toys, air conditioners, refrigerators, electrical machines switch gear manufacturing units, etc.

Make of spot welding machine : Gem spot weld
Model of spot welding machine : GEM SP/6
KVA Rating : 6 KVA
Main supply 50 cycles : 400V of 3 Ph
Frequency : 50 Hz
Max. Electrode force : 3924 N
Max. Iron & steel welding thickness: 1.6+1.6mm
Electrode diameter : 11.5 mm
Timer : 1 to 10 seconds

Figure 2. Spot welding machine.

3. Fabrication of corrugated Panels:

The experimentation of the thesis is based on Taguchi's Design of Experiments (DOE) and orthogonal array where the input parameters are Spot welding pattern, Sheet thickness, Core height, Shape of the panel, Core shape and Material combination. Remaining spot welding parameters like Squeezing time, Electrode force and Electrode diameter kept constant. According to the six input parameter, Core Height and Panel Shape have three levels and Material combination, Core Shape, Gauge of the sheet and Spot welding pattern are have two levels. The Design of Experiment (DOE) is an effective approach to optimize the output in various manufacturing-related processes. The DOE with L36 levels have been implemented to select best manufacturing parameters which results in the best product. The Shear Stress,Von Mises stress and Deformation panel are investigated. The L36 orthogonal array was used for this study. By Spot welding process the corrugated panels were fabricated and the shear stress of panel, von-mises stress and deformation are determined by Universal Testing Machine.

Material Combination, Core Shape, Face Sheet Thickness, Core Height, Panel Shape and Spot Welding Pattern are considered as design parameters to determine their effect on the Flexural Modulus of the Sandwich panel. A total of 36 experiments based on Taguchi L36 mixed level orthogonal array were carried out with mixed combinations of the input parameters, the material combinations presented are "SSMS" & "SSSS" in which the first two letters indicates face plates and the next two letters indicate core material (i.e., SSMS indicates-Stainless Steel face plates & Mild steel core material; Similarly, SSSS indicates both core and face plates are made of stainless steel). The second parameter considered is core shape which is Rectangular (R) and Dove-tail (V) corrugated sheets as the core materials for the panel. Sheet Gauge is also considered as one of the parameter for the analysis. Two gauges were considered i.e. 20 and 18. The other factor here considered is the spot welding pattern i.e., Linear pattern and Zigzag pattern. The other important parameters for minimizing the volume fraction are the core height such as 20mm, 24mm & 28 mm and the panel shapes are rectangular & square.

Table 3. Various Combinations of Input Parameters

S.No	Parameter	Level-1	Level-2	Level-3
1	Material Combination (MC)	SSMS Face sheet core X	SSSS Face sheet core X	
2	Core Shape (CS)	R- Rectangular Core	V- Shaped Core	
3	Gauge of the sheet (GS)	20 Gauge	18 Gauge	
4	Spot Welding Pattern (SP)	L	Z	
5	Core Height (CH)	20mm	24mm	28mm
6	Panel Shape (PS)	R1- Rectangular panel of the size 500mm(L) × 250mm(W)	R2- Rectangular panel of size 250mm(L) × 500mm(W)	SQ- Square panel of size 350mm × 350mm

4. Design of experiments:

By Taguchi method L36 are designed. These are mixed levels as they are obtained from the input parameters which have four factors with two levels and two factors with three factors. The input parameters are defined in Table 3 and a series of (experiments) combinations are shown in Table 4.

Table 4. L36 Experiments that are used for designing the Panel

S.NO	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	SSMS	R	20	L	20	R1
2	SSMS	R	20	L	24	R2
3	SSMS	R	20	L	28	SQ
4	SSMS	R	20	L	20	R1
5	SSMS	R	20	L	24	R2
6	SSMS	R	20	L	28	SQ
7	SSMS	R	18	Z	20	R1
8	SSMS	R	18	Z	24	R2
9	SSMS	R	18	Z	28	SQ
10	SSMS	V	20	Z	20	R1
11	SSMS	V	20	Z	24	R2
12	SSMS	V	20	Z	28	SQ
13	SSMS	V	18	L	20	R2
14	SSMS	V	18	L	24	SQ
15	SSMS	V	18	L	28	R1
16	SSMS	V	18	Z	20	R2
17	SSMS	V	18	Z	24	SQ
18	SSMS	V	18	Z	28	R1
19	SSSS	R	18	Z	20	R2
20	SSSS	R	18	Z	24	SQ
21	SSSS	R	18	Z	28	R1
22	SSSS	R	18	L	20	R2
23	SSSS	R	18	L	24	SQ
24	SSSS	R	18	L	28	R1
25	SSSS	R	20	Z	20	SQ
26	SSSS	R	20	Z	24	R1
27	SSSS	R	20	Z	28	R2
28	SSSS	V	18	L	20	SQ
29	SSSS	V	18	L	24	R1
30	SSSS	V	18	L	28	R2
31	SSSS	V	20	Z	20	SQ
32	SSSS	V	20	Z	24	R1
33	SSSS	V	20	Z	28	R2
34	SSSS	V	20	L	20	SQ
35	SSSS	V	20	L	24	R1
36	SSSS	V	20	L	28	R2

5. Experimental observation for Three Point Bending:

Bending test determines the flexural rigidity of the material. There are two types of bending tests. They are: Three Point Bending Test and Four Point Bending Test. In this study three point bending test is done. The key analysis while performing bending tests is:

- Flexural Modulus – It is the ratio of stress to strain in flexural deformation, or the tendency for a material to bend. It is determined from the slope of a stress-strain curve produced by a flexural test, and uses units of force per area.
- Flexural Strength - a mechanical parameter for brittle material is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol σ.

- Yield Point - load at which a solid material that is being stretched begins to flow, or change shape permanently, divided by its original cross-sectional area; or the amount of stress in a solid at the onset of permanent deformation

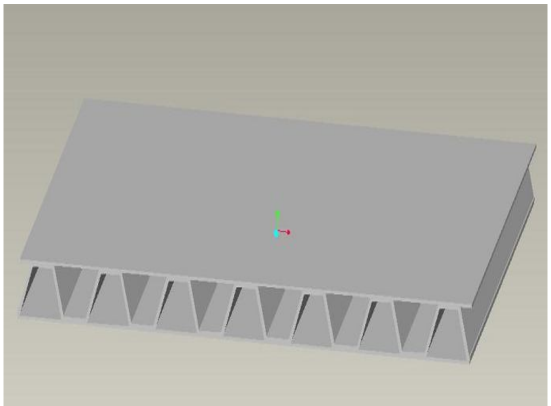

Figure 3. 3D Model of V-Panel for Numerical Analysis

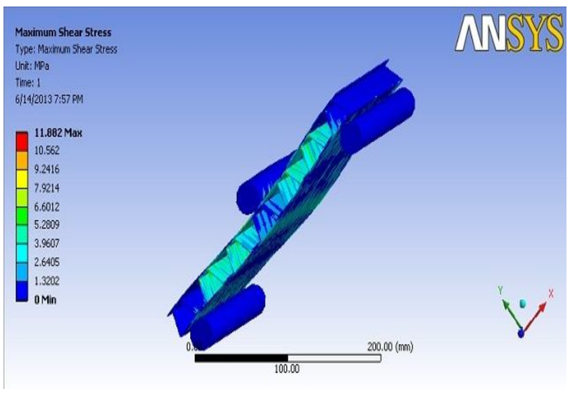

Figure 4. FEA Results for Maximum shear stress

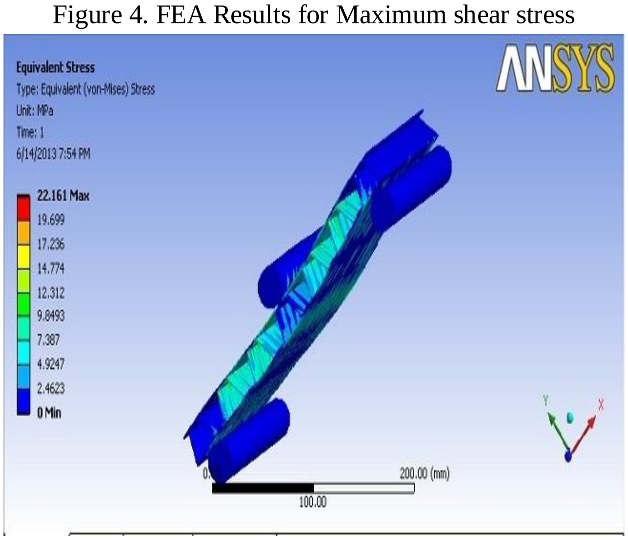

Figure 5. FEA Results for Maximum Von-misses stress

Figure 6. Experimental test of three point bending test

Figure 7. Tested panel in three point bending test

Figure 4 represents the 3D Model of V-Panel for numerical analysis. Figure 5 represents the FEA of panel in ANSYS workbench for Maximum Shear Stress. Figure 6 represents the FEA of panel in ANSYS workbench for Von Mises Stress. The experimental setup is shown in the Figure 7 where the panel is ready to undergo three point bending test. The Figure 5 shows the panel after it is being tested.

6. Evaluation of Experiments obtained:

Table 5. Outputs of L36 Experiments

S. No	Von Misses Stress	Deformation	Shear Stress
1	137.71	0.3332	75.328
2	105.69	0.22843	59.709
3	137.68	0.45744	77.523
4	137.71	0.3332	75.328
5	105.69	0.22843	59.709
6	137.68	0.45744	77.523
7	137.29	0.33038	75.096
8	25.394	0.094139	14.164
9	68.8	0.23172	38.264
10	113.26	0.39075	59.884

11	49.454	0.13016	27.431
12	60.302	0.14519	34.228
13	22.075	0.09827	11.944
14	43.272	0.13129	22.846
15	89.842	0.33685	46.983
16	22.075	0.09827	11.944
17	43.272	0.13129	22.846
18	89.842	0.33685	49.983
19	15.769	0.017551	8.741
20	94.987	0.19447	53.981
21	96.627	0.50398	47.949
22	15.769	0.017551	8.741
23	94.987	0.19447	53.981
24	96.627	0.50398	47.949
25	73.927	0.10313	38.167
26	233.99	0.69529	132.31
27	73.383	0.19827	41.97
28	49.818	0.14367	26.358
29	105.45	0.37319	54.884
30	23.958	0.19047	13.742
31	89.815	0.17262	50.304
32	116.67	0.46334	60.287
33	40.6	0.12289	22.81
34	89.815	0.17262	50.304
35	116.67	0.46334	60.287
36	40.6	0.12289	22.81

The experiments obtained from the DOE by Taguchi method using input parameters and their levels are L36 experiments. These experiments are analyzed on ANSYS workbench to determine the Shear Stress, Von-Mises Stress and Deformation which are later evaluated with experiment results. For all the conditions the maximum load is considered to be 5000N. The values of Von-Mises Stress, Shear Stress and Deformation are tabulated in Table 5 from which the optimized parameters are obtained.

III. RESULTS AND DISCUSSIONS

1. Analysis of Taguchi Designs:

Signal to noise ratio

- Calculation of the S/N ratio depends on the experimental objective.
- Taguchi is emphasis on minimizing deviation from target lead him to develop measures of the process output that incorporate both the location of the output as well as the variation. These measures are called signal to noise ratios.
- The signal to noise ratio provides a measure of the impact of noise factors on performance. The larger the S/N, the more robust the product is against noise.

2. Results for Von-Misses Stress:

The L36 experiments that were conducted and their respective Von-Mises Stress obtained in Table 5. The influence the effect of Spot welding pattern, Sheet gauge, Panel shape, Core height, Core shape and Material combination on Von Mises Stress is predicted to get the optimum values respective parameters.

In Taguchi design each factor is individually analyzed. For Von-Mises stress the maximum value has to be as small as possible. Therefore “Smaller is better” option is selected while analyzing it. The S/N ratios are obtained which are later used for doing Grey Relational Analysis.

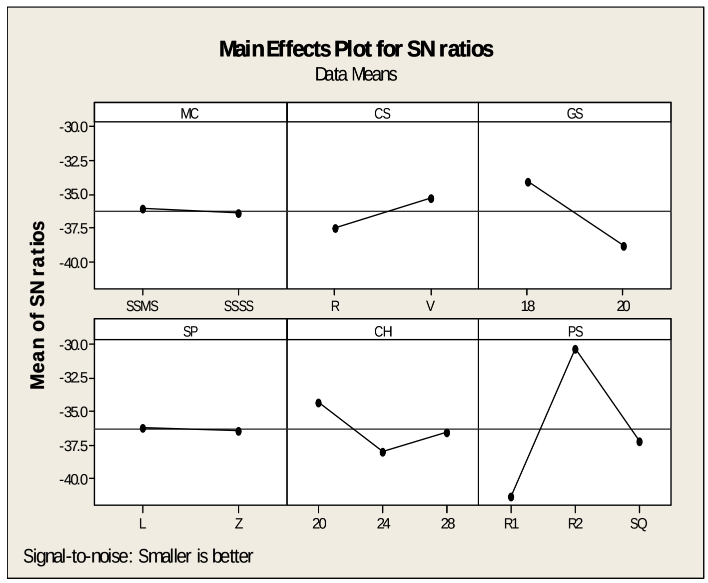

Figure 8. Graph of Main Effects for S/N Ratios

Response Table for Signal to Noise Ratios Smaller is better

Table 6. Response Table for S/N Ratios for Von Mises Stress

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	-36.10	-37.48	-34.08	-36.17	-34.34	-41.33
2	-36.42	-35.28	-38.92	-36.37	-37.96	-30.31
3					-36.54	-37.20
Delta	0.32	2.19	4.85	0.21	3.62	11.03
Rank	5	4	2	6	3	1

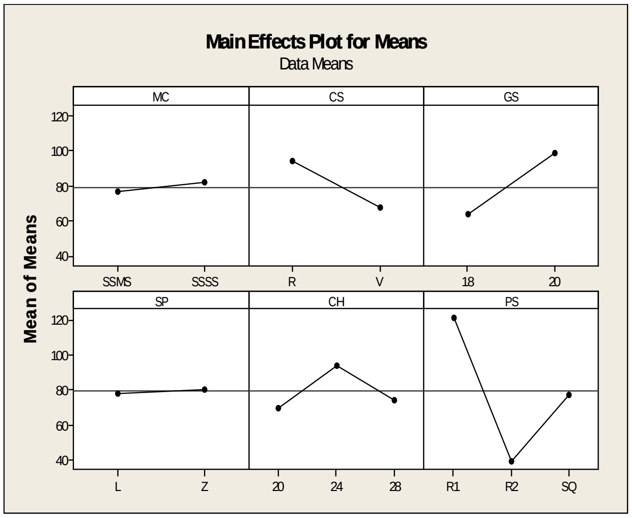

Figure 9. Graph of Main Effects for Means

Response Table for Means

Table 7. Response Table for Means for Von Mises Stress

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	76.40	93.91	63.10	78.00	69.76	121.27
2	81.64	67.04	98.64	80.30	93.62	39.52
3					74.39	76.97
Delta	5.24	26.86	35.53	2.31	23.86	81.75
Rank	5	3	2	6	4	1

The above S/N ratio table shows the parameter that influences the Von Misses stress the most is Panel Shape followed by Sheet Gauge, Core shape, Core height and Material Combination and finally Spot Welding Pattern.

Similarly for the response table for Means the parameter that influence are in order starting with Panel Shape, Gauge of Sheet, Core Shape, Core Height, Material Combination and Spot Welding Pattern. The graph of S/N ratios and Means shows the response of each factor with respect to the Von-Mises Stresses.

3. Results for Deformation:

The L36 experiments that were conducted and their respective Deformation are obtained in Table 5. The influence the effect of Spot welding pattern, Sheet gauge, Panel shape, Core height, Core shape and Material combination on Deformation is predicted to get the optimum values respective parameters.

Since the deformation has to be smaller the option "Smaller is better" is selected. The plots of each parameter response individually are represented in the S/N ratio graph. The plot for main effects of means is also obtained. The following are the graphs of the parameters response with respect to Deformation:

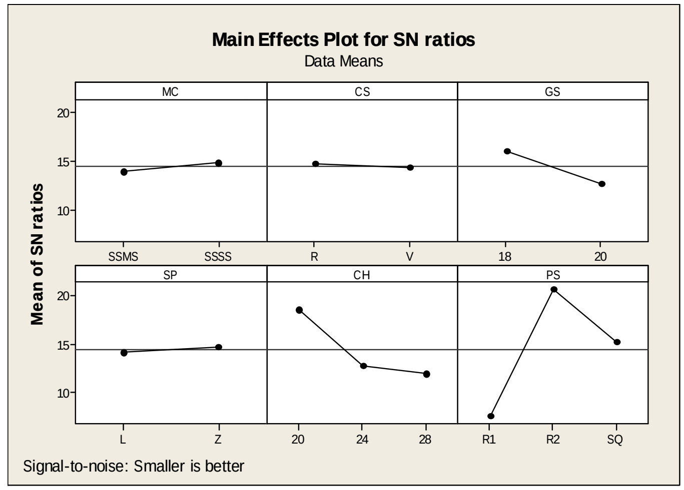

Figure 10. Graph of Main Effects for S/N Ratios

Response Table for Signal to Noise Ratios
Smaller is better

Table 8. Response Table for S/N Ratios for Deformation

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	13.941	14.635	12.603	14.111	18.633	7.565
2	14.869	14.290	15.984	14.728	12.714	20.588
3					11.994	15.188
Delta	0.928	0.345	3.381	0.617	6.638	13.023
Rank	4	6	3	5	2	1

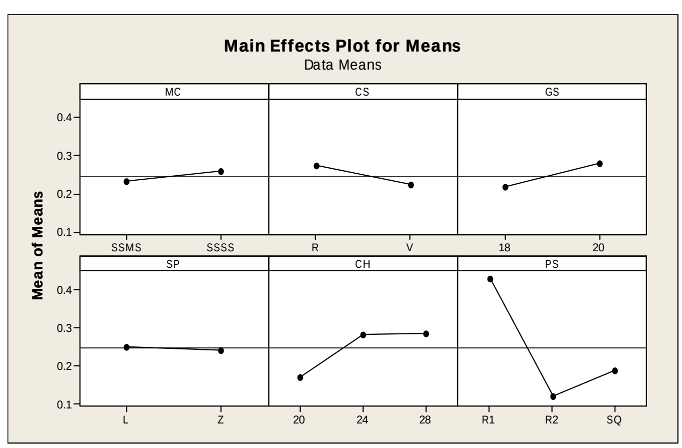

Figure 11. Graph of Main Effects for Means

Response Table for Means

Table 9. Response Table for Means for Deformation

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	0.2316	0.2736	0.2800	0.2512	0.1707	0.4301
2	0.2585	0.2236	0.2182	0.2422	0.2818	0.1199
3					0.2864	0.1889
Delta	0.0269	0.0500	0.0617	0.0089	0.1157	0.3102
Rank	5	4	3	6	2	1

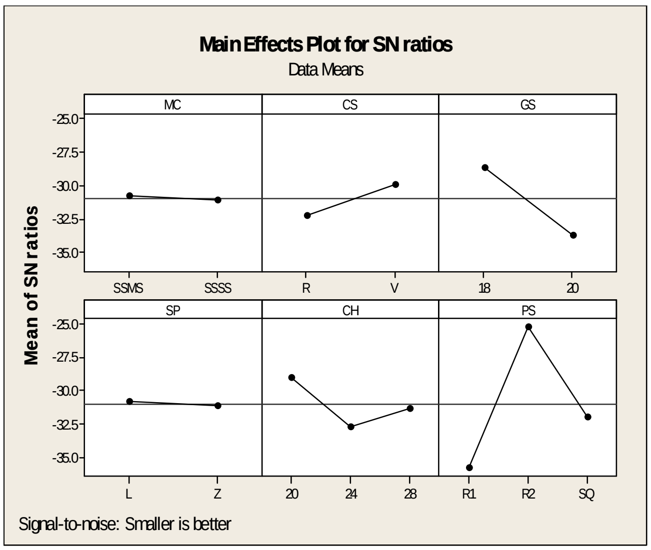

Figure 12. Graph of Main Effects for S/N Ratios

The above S/N ratio table shows the parameter that influences the Deformation the most is Panel Shape followed by Core height, Gauge of the Sheet, Material Combination, Spot Welding Pattern and finally Core shape. Similarly for the response table for Means the parameter that influence are in order starting with Panel Shape, Core Height, Gauge of the Sheet, Core Shape, Material Combination and Spot Welding Pattern. The S/N ratios are used to conduct the Grey Relational Analysis in the later section.

4. Results for Shear Stress:

The L36 experiments that were conducted and their respective Shear stress are obtained in Table 5. The influence the effect of Spot welding pattern, Sheet gauge, Panel shape, Core height, Core shape and Material combination on Shear stress is predicted to get the optimum values respective parameters. Since the Shear Stress has to be smaller the option as “smaller is better” is selected. The plots of each parameter response individually are obtained in the S/N ratio graph. The plot for main effects of means is also obtained. The following are the graphs of the parameters response with respect to Shear Stress:

Response Table for Signal to Noise Ratios
Smaller is better

Table 10. Response Table for S/N Ratios for Shear Stress

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	-30.86	-32.25	-33.73	-30.86	-29.04	-35.79
2	-31.13	-29.97	-28.73	-31.13	-32.67	-25.24
3					-31.30	-31.99
Delta	0.27	2.28	5.00	0.27	3.63	10.55
Rank	6	4	2	5	3	1

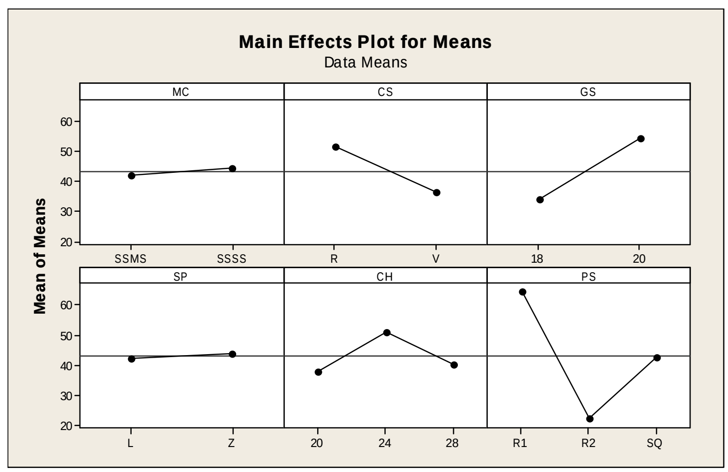

Figure 13. Graph of Main Effects for Means

Response Table for Means

Table 11. Response Table for Means for Shear Stress

Level	Material Combination	Core Shape	Gauge of the Sheet	Spot Welding Pattern	Core Height	Panel Shape
1	41.88	51.59	54.22	42.23	37.89	64.63
2	44.20	36.10	33.91	43.91	51.16	22.18
3					40.38	42.62
Delta	2.32	15.49	20.31	1.68	13.27	42.45
Rank	5	3	2	6	4	1

The above S/N ratio table shows the parameter that the influence the Shear stress the most is Panel Shape followed by Sheet Gauge, Core shape, Core height, Material Combination and finally Spot Welding Pattern. Similarly for the response table for Means the parameter that influence are in order starting with Panel Shape, Gauge of Sheet, Core Shape, Core Height, Material Combination and Spot Welding Pattern.

The above section of chapter deals with the graphs regarding the influence of input parameters on Von Mises stress, Deformation and Shear stress of the L36 experiments. The values of the Delta and ranks of the parameters have been taken as inputs to the experiment such as Material Combination, Panel Shape, Core Height, Gauge of the Sheet and Core Shape are discussed.

5. Grey Relational Analysis for Corrugated Sandwich Panels:

In the present study, Von Mises Stresses, Shear Stresses and Deformation are responses that have "smaller the better" characteristics. The equations shown in the section 3.4 are used here to calculate the Grey relational coefficients and Grey Grades. Table 5.7 lists the S/N ratios each output of Von-Mises Stress, Deformation and Shear Stress and are then normalized to find the Grey Relational Coefficients, the Grey Grades and finally Average Grey Grade.

Table 12. S/N Ratio Values of Output Parameters

S. No	Von-Mises Stress	Deformation	Shear Stress
1	-42.7793	9.5459	-37.5391
2	-40.4807	12.8249	-35.5208
3	-42.7774	6.7933	-37.7886
4	-42.7793	9.5459	-37.5391
5	-40.4807	12.8249	-35.5208
6	-42.7774	6.7933	-37.7886
7	-42.7528	9.6197	-37.5123
8	-28.0946	20.5246	-23.0237
9	-36.7518	12.7007	-31.6558
10	-41.0815	8.1620	-35.5462
11	-33.8840	17.7104	-28.7648
12	-35.6066	16.7613	-30.6876
13	-26.8780	20.1516	-21.5430
14	-32.7241	17.6354	-27.1762
15	-39.0696	9.4513	-33.4388
16	-26.8780	20.1516	-21.5430
17	-32.7241	17.6354	-27.1762
18	-39.0696	9.4513	-33.9764
19	-23.9561	35.1140	-18.8312
20	-39.5533	14.2229	-34.6448
21	-39.7020	5.9517	-33.6156
22	-23.9561	35.1140	-18.8312
23	-39.5533	14.2229	-34.6448
24	-39.7020	5.9517	-33.6156
25	-37.3761	19.7323	-31.6338
26	-47.3839	3.1567	-42.4319
27	-37.3119	14.0549	-32.4588
28	-33.9477	16.8527	-28.4182
29	-40.4609	8.5614	-34.7889
30	-27.5890	14.4035	-22.7610
31	-39.0670	15.2582	-34.0321
32	-41.3392	6.6820	-35.6045
33	-32.1705	18.2097	-27.1625
34	-39.0670	15.2582	-34.0321
35	-41.3392	6.6820	-35.6045
36	-32.1705	18.2097	-27.1625

Table 13. Normalized Values for S/N Ratio Values of Output Parameters

S. No	Von-Mises Stress	Deformation	Shear Stress
1	0.196544	0.199929	0.207315
2	0.294658	0.302534	0.292834
3	0.196625	0.113795	0.196744
4	0.196544	0.199929	0.207315
5	0.294658	0.302534	0.292834
6	0.196625	0.113795	0.196744
7	0.197675	0.202238	0.208451
8	0.823350	0.543472	0.822356
9	0.453824	0.298648	0.456600
10	0.269013	0.156624	0.291758
11	0.576234	0.455410	0.579097
12	0.502706	0.425711	0.497625
13	0.875280	0.531800	0.885096
14	0.625743	0.455410	0.646408
15	0.354890	0.425711	0.381052
16	0.875280	0.531800	0.885096
17	0.625743	0.453063	0.646408
18	0.354890	0.196969	0.381052
19	1	1	1
20	0.334243	0.346280	0.329952
21	0.327896	0.087460	0.373560
22	1	1	1
23	0.334243	0.346280	0.329952
24	0.327896	0.087460	0.373560
25	0.427176	0.518679	0.457533

26	0	0	0
27	0.429916	0.341023	0.422576
28	0.573515	0.428571	0.593783
29	0.295503	0.169122	0.323846
30	0.844932	0.351932	0.833487
31	0.355001	0.378677	0.355913
32	0.258013	0.110312	0.289288
33	0.649373	0.471034	0.646989
34	0.355001	0.378677	0.355913
35	0.258013	0.110312	0.289288
36	0.649373	0.471034	0.646989

Table 14. Grey Relational Coefficients and Grey Grade

Experiment No	Grey Relation Coefficients			Grey Grade
	Von-Mises stresses in MPa	Shear Stress in MPa	Deformation in mm	
1	0.383595	0.386791	0.384594	0.384993
2	0.414820	0.414193	0.417548	0.415520
3	0.383619	0.383654	0.360697	0.375990
4	0.383595	0.386791	0.384594	0.384993
5	0.414820	0.414193	0.417548	0.415520
6	0.383619	0.383654	0.360697	0.375990
7	0.383928	0.387132	0.385278	0.385446
8	0.738934	0.737850	0.522723	0.666502
9	0.477931	0.479202	0.416197	0.457777
10	0.406178	0.413828	0.372196	0.397400
11	0.541262	0.542945	0.478656	0.520954
12	0.501356	0.498815	0.465424	0.488531
13	0.800358	0.813135	0.516422	0.709971
14	0.572569	0.585759	0.478656	0.545661
15	0.436639	0.446848	0.465424	0.449637
16	0.800358	0.813135	0.516422	0.709971
17	0.572569	0.585759	0.476355	0.545661
18	0.436639	0.446848	0.383720	0.449637
19	1	1	1	1
20	0.428905	0.427332	0.433380	0.429872
21	0.426583	0.443876	0.353972	0.408143
22	1	1	1	1
23	0.428905	0.427332	0.433380	0.429872
24	0.426583	0.443876	0.353972	0.408143
25	0.466059	0.479631	0.509517	0.485069
26	0.333333	0.333333	0.333333	0.333333
27	0.467253	0.464069	0.431414	0.454245
28	0.539674	0.551744	0.466666	0.519361
29	0.415111	0.425114	0.375691	0.405305
30	0.763279	0.750172	0.435514	0.649655
31	0.436681	0.437029	0.445901	0.439870
32	0.402580	0.412980	0.359792	0.391784
33	0.587801	0.586158	0.485924	0.553294
34	0.436681	0.437029	0.445901	0.439870
35	0.402580	0.412980	0.359792	0.391784
36	0.587801	0.586158	0.485924	0.553294

Table 15. Average Grey Grade for Design Parameters

LEVELS	MC	CS	GS	SP	CH	PS
1	0.482230	0.489522	0.433468	0.491975	0.571412	0.399216
2	0.512627	0.508980	0.565034	0.506527	0.457647	0.637410
3					0.468694	0.461127

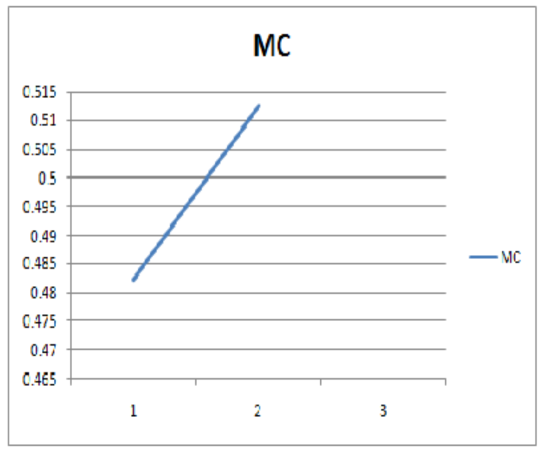

Figure 14. (a)Material Combination

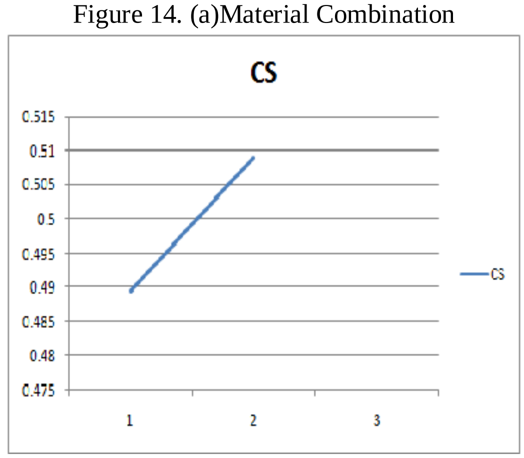

Figure 15. (b) Core Shape

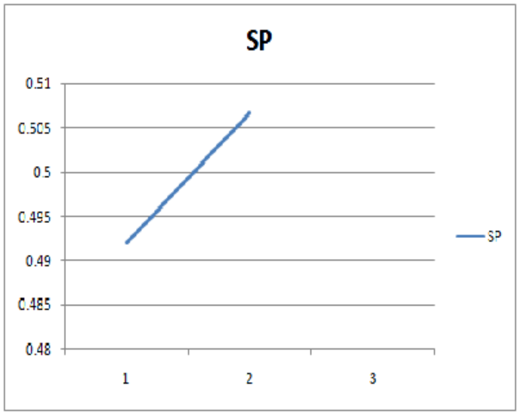

Figure 16. (c) Gauge of Sheet

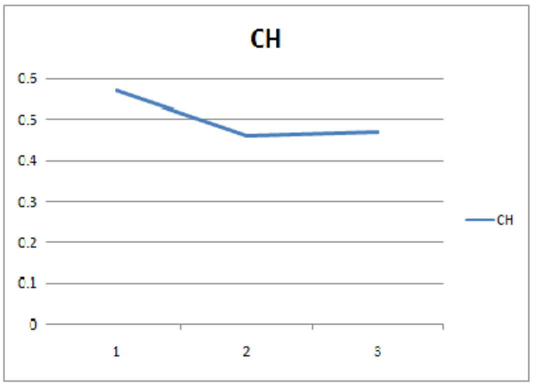

Figure 17. (d) Spot Welding Pattern

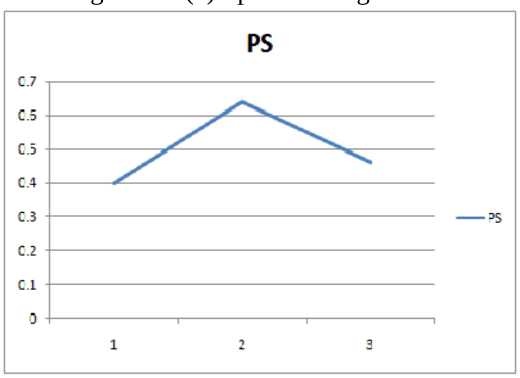

Figure 18. (e) Core Height

Graphs for Average Grey Grades of all the Design Parameters

The Table 15 shows values of grey relational grade for factors Material Combination, Core Shape, Gauge of the Sheet, Spot Welding Pattern, Core Height, and Panel Shape respectively. Largest values are considered optimum values therefore Material combination at level 2, Core shape at level 2, Gauge of the Sheet at level 2, Spot Welding Pattern at level 2, Core height at level 1, Panel shape at level 2 are the conditions for the optimal design parameter combination of corrugated sandwich panel to minimize Von-mises stresses, Shear stresses, and Deformation. The influence of each parameter can clearly presented by means of the grey relational grade graph. It shows the change in responses.

According to the values predicted from the Taguchi Design it indicates that SSMS is better to minimize the Von-Mises Stress and Shear Stress where as SSSS is better to minimize deformation. But the Grey Relational Analysis shows when all the parameters are considered it is better to go with SSSS which is Stainless Steel Core Sheet and Stainless Steel Face Sheet.

The Values of Taguchi Design Predict that Core Shape of the panel to minimize the Von-Mises Stress and Shear Stress must be V Shaped where as the Core Shape to minimize the Shear Stress must be Rectangular Shaped. By combining all the parameters and finding the best shape by Grey Relational Analysis it predicts that V Shaped Core is better.

Gauge 18 is supported by both Grey Relational Analysis and Taguchi Method to minimize the Von-Mises Stress, Deformation and Shear Stress. Similarly the Core Height predicted by Taguchi Design and Grey Relational Analysis to minimize the Von Mises Stress, Deformation and Shear Stress is 20mm.

According to Taguchi Design the Spot Welding Pattern to optimize Von Mises Stress and Shear Stress must be Linear and for Deformation to be less it must be Zig-Zag. After Grey Relational Analysis the Zig-Zag Pattern is considered better for optimizing the Von Mises Stress, Deformation and Shear Stress.

Finally the Shape of the Panel predicted by both Taguchi Design and Grey Relational Analysis is R2 – Rectangular Panel of size 500mm(L)* 250mm(W) for minimization of Von Mises Stress, Deformation and Shear Stress.

Table 16. Optimized Values of Design Parameters

S.NO	**Design Parameter**	**Optimized Values**
1	Material Combination	SSSS
2	Core Shape	V – Shaped
3	Gauge of the Sheet	18
4	Spot Welding Pattern	Zig-Zag
5	Core Height	20mm
6	Panel Shape	R2 – Rectangular panel of size 500mm(L)*250mm(W)

6. Compression Test on Corrugated Panel with Optimized Parameters:

With above optimized parameters we have checked whether we have an experiment with those values in the L36 experiments. We find that no such kind of experiment has been evaluated. So we consider the following design values and construct a panel according to the optimized values.

After construction of the panel we conduct the compression test for the panel and find the compression load that it can withstand. The compression test is done on Ultimate Tensile Machine. The maximum compression load is 179KN. Here the final values taken for the fabrication the panel are Material combination as “SSSS”, Core Height as 20mm, V - Shaped Corrugated sheet, Spot Welding Pattern as Zig-Zag and Gauge of the Sheet as 18. The following are the results of maximum compression load and respective graphs:

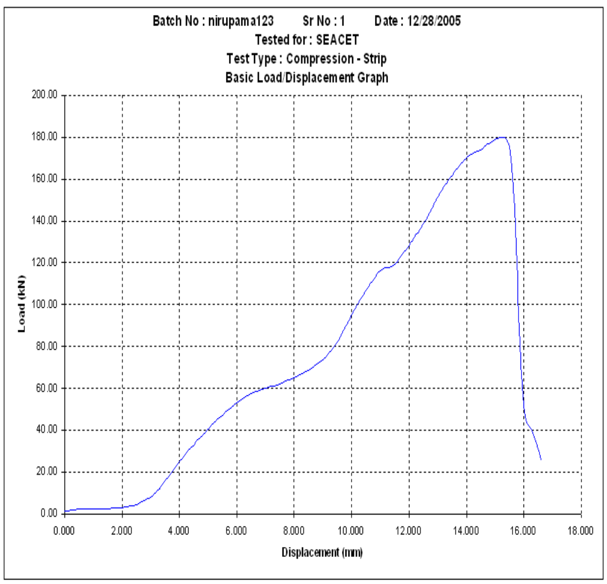

Figure 19. Load Vs Displacement Graph for Fabricated Panel.

IV. CONCLUSIONS & SCOPE OF FUTURE WORK

Conclusions:

- This thesis is presented to design and fabricate corrugated panel. The analysis is done by application of design of experiment by Taguchi method. The elaborative conclusion of present analysis of corrugated panels is:
- From the Taguchi Design and Grey Relation Analysis it is observed that optimum parameters are SSSS Material Combination, V Shape Core Shape, 18 Gauge of the Sheet, 20 mm Core Height, R2-Rectangular Panel of 500mm (L) x 250mm (W) panel shape and the Spot Welding Pattern must be Zig-Zag.
- With the above parameters there is no such experiment in the L36 experiments we have done so we assume the different experiment with this set of parameters and design the panel and conduct Compression Test on that panel.
- To join the core and face sheets Spot Welding technique is selected. To design this particular panel a special electrode has been designed.
- The maximum load the panel can carry is calculated through Load vs. Displacement graph as 179.2 KN which is three times than the normal panels.

1. Applications and Scope for Future Work:

Corrugated panels are widely used in automobile and construction fields. Now a day’s slowly the application of the panels is extended to home appliances’ where lots of research is going on. In case of automobiles panels are used for building the body whereas in ships decks are made from the corrugated panels. With the use of these panels the weight reduces hence the capacity increases. These panels are used in roof structures and in elevations as the desired shape is obtained easily with more strength. In past decades wood is used for partition walls which needs more maintenance are being replaced by panels. The life of the panels is more and the maintenance is less hence is widely used in interior designs. In automobile industry corrugated panels are playing the role of composite materials. The following figure shows the wide range of applications of corrugated panels.

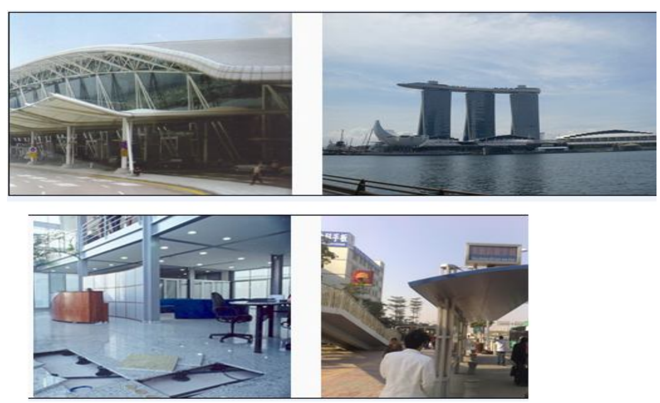

Figure 20.

Scope for future work

- The panels have to be tested for buckling loads
- The panels have to be tested for impact loads
- Lot of analysis has to be taken up on the shape, size and position of the cutouts in the panels
- Analysis has to be carried on the joining process of the Core and Face sheets.
- In future the application of the panels may be extended to home appliances’.

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